

The Impact of Interconnections on Reliability Contribution of Wind Farms

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Abstract— This paper studies reliability benefits of wind energy in two different systems in Australia: New South Wales and Victoria. Reliability assessment has been conducted in generation system level and a time dependent clustering method is applied to model wind power. This technique not only can capture time dependent attributes of wind energy, but also is capable of keeping the correlations between wind power and demand. Furthermore, different scenarios have been studied to investigate the impact of interconnectors on the reliability benefit of wind farms. Results show that the impact of exchanged power through tie lines can be dissimilar for different systems and is mainly related to the direction of the flowing power.

Index Terms—Generation adequacy, Monte Carlo method, reliability assessment, load carrying capability, wind power.

I. INTRODUCTION

Renewable energies are growing fast due to government support and their low generation costs. Amongst clean technologies, wind turbine is the most popular one. However, these renewable generators have brought new challenges to power systems. Main difficulties of these units are due to uncertainty and fluctuation in their output power, which can affect operation and reliability of electricity networks [1]. Therefore, it is necessary to investigate the impact of wind resources and their contribution to reliability of power grid.

Several techniques have been proposed to model wind generators in reliability studies. Multistate generator [1], negative load [2], clustered model [3] and probabilistic model [4] are some of these methods. In this work, a time dependent clustering technique [5] is applied to model wind power. This method models wind output, load and exchanged power as time dependent clusters to keep the correlation between them and capture their time dependent features. In addition, as this technique is not using chronological data, it is efficient in term of computational time [5].

Wind generation is increasing in Australia and its installed wind capacity is expected to grow to 11.5 GW by 2020 [6]. Among the Australian states, the share of Victoria and New South Wales in newly integrated wind farms is expected to be the highest, with 4,090MW and 2,117MW projected new wind

by 2020 respectively [6]. Since the participations of wind power producers in these states are becoming more significant, the contribution of them in reliability of these networks should be evaluated. In addition, Victoria and New South Wales have several connections with other states and exchange a considerable amount of electricity through these tie lines. Therefore, in this paper the impact of the interconnectors on the reliability benefits of wind energy in these power systems is investigated.

II. CASE STUDIES

New South Wales (NSW) and Victoria (VIC) have the highest demand and generation capacity in Australia and are connected to other states through several interconnectors. In 2014, the total generation capacity of NSW was 16,835MW, while VIC had around 12,330MW, and the majority of electricity in both of these networks is from coal based power plants [7]. Fig. 1 illustrates the contribution of different generators type in the total generation capacity of New South Wales and Victoria. It can be seen that the share of coal and gas generators in both states is above 70%. In NSW, the installed capacity of hydro power plants is 2,745MW which is 16% of total generation, whereas, in Victoria the contribution of water in generating electricity is 2,296MW (18.6%) [7].

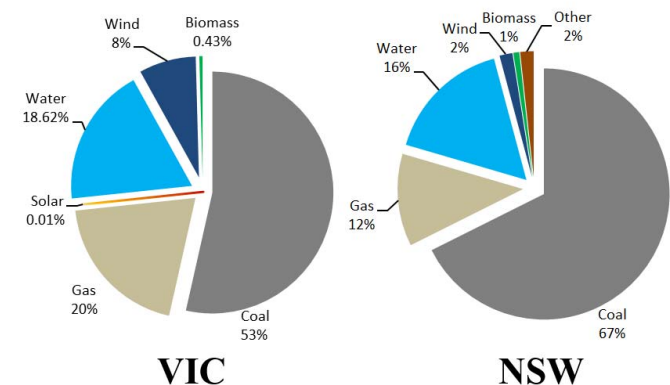


Figure 1. VIC and NSW generation capacity percentage by generation type in 2014 [7]

Wind energy has the fourth place in producing electricity in both states; however, the share of wind farms in Victoria is much higher than NSW. There were around 900MW installed wind farms in VIC in 2014, while the installed capacity of wind farms in NSW was around 270MW. Details of the New South Wales and Victorian wind farms which have been considered in this study are presented in Table I [6].

TABLE I. EXISTING NEW SOUTH WALES AND VICTORIA WIND FARMS [6]

Wind Farm	Capacity (MW)	Capacity Factor (%)
New South Wales		
Capital	140	39.85
Cullerin	30	39.97
Gunning	47	37.51
Woodlawn	48	39.85
Victoria		
Challicum Hills	53	34.08
Macarthur	420	36.62
Mortons Lane	20	36.62
Oaklands Hill	67	38.14
Portland	102	39.74
Waubra	192	38.48
Yambuk	30	39.74

It can be seen that most of the Victorian wind farms have a capacity factor lower than wind farms in NSW. Total wind generation in NSW and VIC from 2013 till the end of 2014 are demonstrated in Fig. 2 and Fig. 3, respectively [8]. They show that the output of wind farms in NSW can vary from zero megawatt to 260MW, while in VIC total wind generation fluctuates from 0MW up to 850MW.

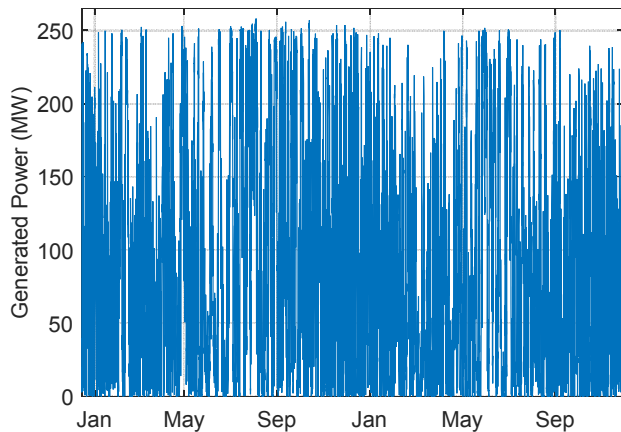


Figure 2. Total wind generation in NSW for 2013-2014 [8]

The peak demand in NSW between 2013 and 2014 was around 14,000MW and the minimum demand was close to 5,000MW, while in VIC, during the same period, these values were 10,000MW and 3,200MW, respectively [9]. The average hourly electricity load in NSW and VIC from 2013 to 2014 is depicted in Fig. 4 [9].

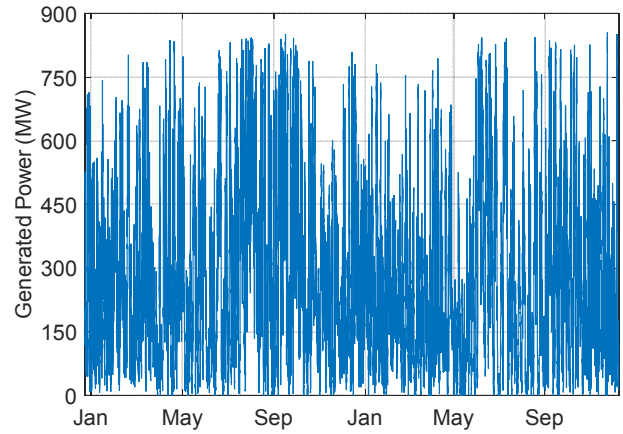


Figure 3. Total wind generation in VIC for 2013-2014 [8]

From Fig. 4 it can be seen that the average hourly load profiles in these two systems are similar. The average demand in both states has two peak periods and is low during midnight and early morning.

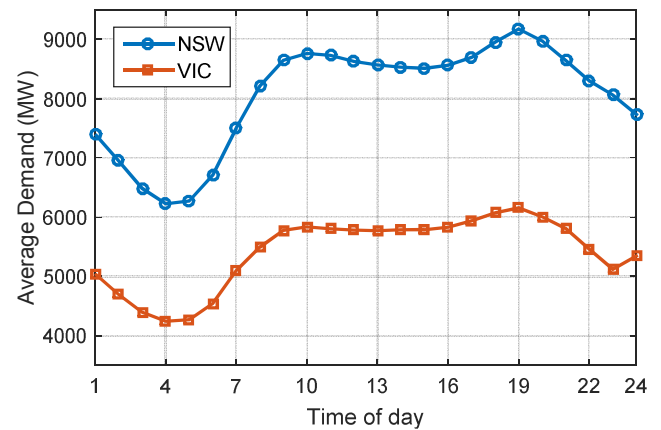


Figure 4. Average hourly demand in VIC and NSW for 2013-2014

New South Wales network is connected to the Queensland and Victoria power systems through three interconnectors. From Terranora in NSW to Mudgeeraba in Queensland there are three 110 kV DC lines known as Directlink interconnector. The other tie line is the Queensland to New South Wales (QNI) interconnector, which is a 330 kV AC interconnection between Dumaresq in New South Wales and Bulli Creek in Queensland. The Victoria to New South Wales interconnector (VNI) consists of 330 kV and 220 kV AC lines. Victorian electricity network has a meshed topology and is connected to three other states: NSW, South Australia (SA) and Tasmania (TAS), via high-voltage interconnectors. Victoria is connected to South Australia through one high voltage AC link (Heywood) and a HVDC interconnector (Murraylink). A HVDC interconnection (Basslink) transfers power between Victoria and Tasmania. Nominal capacities of the tie lines in each direction are presented in Table II [10].

TABLE II. NOMINAL CAPACITY OF NSW AND VIC INTERCONNECTORS [10]

From	To	Nominal Capacity
NSW (Directlink)	Queensland	107 MW
Queensland	NSW	210 MW
NSW (QNI)	Queensland	300-600 MW
Queensland	NSW	1078 MW
NSW	Victoria	400 to 1350 MW
Victoria	NSW	700 to 1600 MW
Victoria	SA (Heywood)	460 MW
SA (Heywood)	Victoria	460 MW
Victoria	SA (Murraylink)	220 MW
SA (Murraylink)	Victoria	200 MW
Victoria	TAS (Basslink)	478 MW
TAS (Basslink)	Victoria	594 MW

It can be observed that for some of these transmission links the capacity limits may change for different power directions. For example, maximum 478MW power can go from Victoria to TAS through Basslink, while this interconnection can transfer up to 594MW in the opposite direction. This table also shows that the capacity of these tie lines in the NSW direction is higher, which is due to frequency, voltage, small signal and transient stability constraints.

Average hourly exported power from NSW and Victoria during 2013 to 2014 is shown in Fig. 5 [8]. Positive values represent the amount of exported power and negative numbers are the amount of imported power.

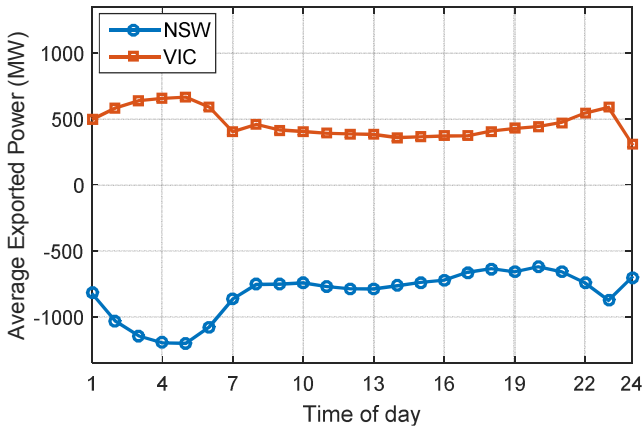


Figure 5. Average hourly exported electricity from VIC and NSW for 2013-2014

It can be seen that the mean value of exchanged power in VIC is around 500MW and in NSW this value is -900MW, which shows that during this period Victoria has mainly exported while NSW has imported electricity through the interconnectors. The highest amount of exported power during this period in VIC was around 2,100MW, while this system has imported more than 1,000MW in some occasions. On the other hand, in NSW, the maximum of exported and imported electricity were about 950MW and 2,500MW, respectively.

III. RELIABILITY ASSESSMENT

In this paper time dependent clustering method [5] is utilized to evaluate the reliability benefits of wind power in VIC and NSW. In this method, load, wind power and exchanged electricity are modelled as time dependent clusters and hourly reliability indices of the system are calculated based on the hourly values of these clusters. This method can be explained briefly as follows.

First, all historical data are classified into twenty-four groups and each group represents a specific time of the day. Then, by means of the Fuzzy C-mean method [11], data points in each of these 24 groups are clustered into proper number of levels. Afterwards, these clusters are sorted successively in accordance with their probability. In the next step, for each model, a uniformly random number between [0, 1] is generated for each hour and the cluster value with the probability related to this number is selected to represent the data in that specific time. This process should be conducted for all wind farms, demand and interconnectors data sets. Then after having these hourly values and by means of state sampling Monte Carlo [12], hourly reliability indices of the system are calculated. Finally, the overall reliability level of the system is computed by taking the average of these hourly values, which is utilized to calculate the effective load carrying capability of wind energy. The process of evaluating New South Wales reliability level is explained in the following to describe this methodology more clearly.

In the first step, the hourly clustered model of NSW demand, wind power and exported electricity should be constructed. Fig. 6 illustrates the time dependent clustered model of load in NSW using historical data from 2013 to 2014. As it can be observed, for each hour there are 10 clusters with different probabilities to represent load value at that time.

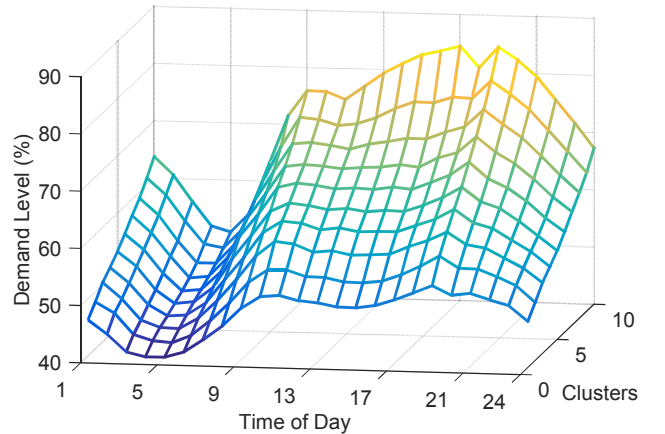


Figure 6. Time dependent clustered model of load data in NSW

Similar models are created for wind farms and tie lines and the probabilities of clusters in each hourly group should meet (1), where P_j is the probability of the j th cluster and n is the total number of clusters in each hour.

$$\sum_{j=1}^n P_j = 1 \quad (1)$$

In the next step, the state sampling Monte Carlo is used to calculate reliability level of the system in the generation system level. For this reason, all generators and electricity consumers are considered to be on same bus and (2) has been employed to model the total equivalent demand [13].

$$D_t = L_t + P_{\text{exp}} - P_{\text{imp}} - P_{Wt} \quad (2)$$

where L_t denotes load value at time t , P_{exp} and P_{imp} are exported and imported power through the interconnectors, respectively, and P_{Wt} is generated wind power at that specific time. Uniformly random numbers are generated to determine the proper values of clustered models, which represent load, wind power and exchanged power for each hour in this equation.

Finally, the reliability index of the system can be calculated by taking the average value of all sample iterations. In this work, Loss of Expected Energy (LOEE) has been selected to evaluate the reliability benefits of wind energy. This index is related to demand not supplied (DNS), which is the difference between total demand (D) and total generation capacity of the system. The formula to calculate this index for N iterations is given in (3).

$$LOEE = \frac{\sum_{s=1}^N DNS_s \times 8760}{N} \quad (3)$$

In order to investigate the reliability benefits of wind energy, the LOEE is calculated and compared for the system with and without wind farms.

IV. CAPACITY VALUE OF WIND POWER

Wind capacity value or effective load carrying capability (ELCC) is an index to measure the reliability benefits of wind farms. ELCC is the amount of load that can be added to the system in the presence of wind generators while maintaining system's reliability level [12]. In this work, the ELCCs of wind farms in VIC and NSW are calculated for two different scenarios. In the first scenario, these networks are considered to work in islanded mode and no power is transferred through the interconnectors. In the second study, the exchanged power through the tie lines is modelled using time dependent clustering technique and once again the ELCC is calculated to investigate the impact of the interconnectors on the reliability benefits of wind energy in these two states.

A. Island Mode

The technique to calculate the ELCC of wind farms is presented in Fig. 7. First, LOEE of NSW without wind energy is calculated using PLEXOS, which is a commercially available electricity market simulation platform developed by Energy Exemplar [14]. The red line represents the reliability level of NSW without wind farms. Then, the same index is calculated in the presence of wind energy by applying the approach that was explained in the previous section. The solid blue line represents the LOEE of NSW with wind farms and for different amount of extra load added to this system.

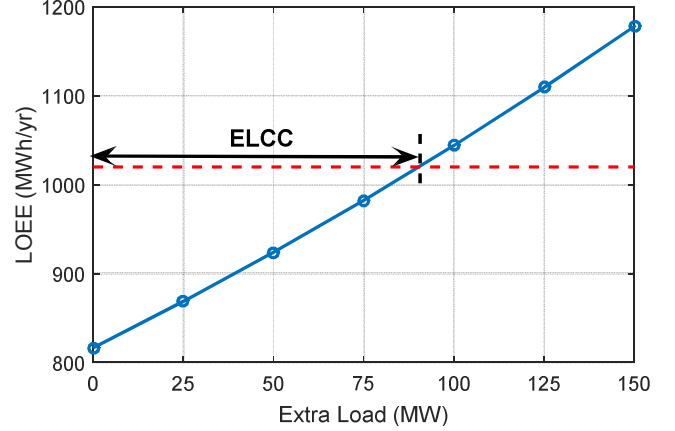


Figure 7. Capacity value of NSW wind farms in island mode

The ELCC of wind energy in New South Wales, as demonstrated in Fig. 7, is around 90MW. It means that this much extra added load can be supplied with 265MW installed wind farms in NSW while the reliability level of this system is unchanged. The same approach has been applied on the Victorian wind farms and the results of the study are presented in Table III. It should be mentioned that as NSW is highly reliable and its original LOEE is very small, the system has been modified and its load has been increased to reach the Australian standard unserved energy level, which is 0.002% [15].

TABLE III. ELCC OF WIND FARMS IN NSW AND VIC

From	ELCC (MW)	ELCC (%)
NSW (265MW)	90.20 MW	34.03
VIC (885MW)	219.8 MW	24.84

It can be observed that although the ELCC of wind farms in Victoria is higher in megawatt, its capacity value in percentage value is lower due to the higher wind installed capacity in Victoria (885MW). One reason might be the lower mean value or capacity factor of wind farms in Victoria, which was shown in Table I. The correlations between wind regime and load profile could be another reason. Table IV compares the average hourly correlations between the NSW and VIC wind power and their demand data.

TABLE IV. AVERAGE HOURLY CORRELATIONS BETWEEN WIND POWER AND LOAD DATA IN NSW AND VIC

From	Correlation Coefficient
NSW	0.5986
VIC	0.3712

As it can be seen, the correlation between wind power and load profile in Victoria is lower than the one in NSW, which might be the main reason of the lower ELCC in this state.

B. Considering Interconnectors

In this section, the impact of exchanged power on the reliability benefits of wind energy is investigated. For this purpose, at first, the time dependant model of the transferred

power through interconnectors is constructed. Fig. 8 displays the time dependent model of exported power from NSW.

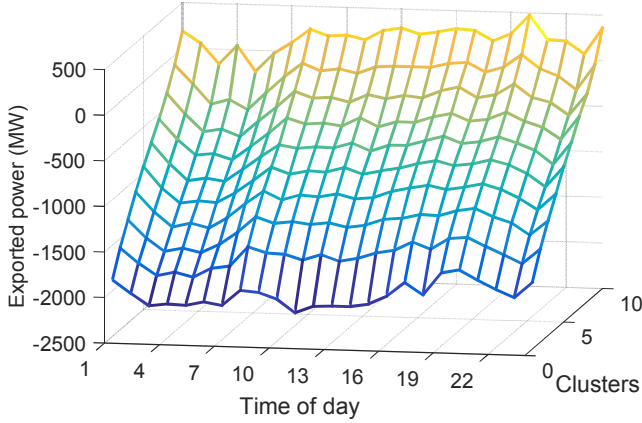


Figure 8. Clustered model of total exported power from NSW

In the next step, the reliability assessment and ELCC calculation is conducted once again. The percentage values of the effective load carrying capabilities of wind power considering the exchanged electricity is illustrated in Fig. 9.

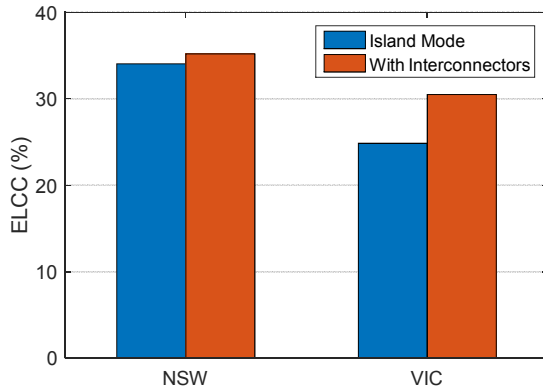


Figure 9. ELCC of NSW and VIC for different scenarios

It can be seen that in the both systems, the ELCC of wind farms in the presence of tie lines has increased. However, the increment in NSW is insignificant in compare to the rise in the ELCC of VIC. The main reason for this might be the different role of the interconnectors in these two states. As it can be observed in Fig. 5, Victoria exports electricity most of the time through these tie lines and the average exported power for this system is positive. On the other hand, NSW uses the interconnectors mainly to import power. Therefore, as the interconnectors are considered and these networks are not islanded anymore, the VIC wind farms can export their generated power to other states when there is no need for them inside Victoria. Whereas, as NSW imports electricity, the contribution of wind is not changing that much and the impact of tie lines on its ELCC is negligible.

V. CONCLUSIONS

The capacity value of wind farms in two different power systems in Australia is evaluated in this paper, and the impact of interconnectors on these values is investigated. Victoria and New South Wales are the case studies, where the share of wind power is expected to grow rapidly in near future. The

time dependent clustering approach is applied to model wind power, electricity demand and exchanged power and the state sampling Monte Carlo technique is implemented to calculate the reliability indices of these systems. Furthermore, two different scenarios are studied to investigate the influence of interconnectors on the ELCC of wind power in these states.

It is shown that the load carrying capability of wind energy is not only related to the wind regime but is also affected by the correlation between wind patterns and load profiles. Moreover, results of the interconnection scenario illustrates that the impact of these power lines on the reliability benefits of wind farms can be different and depends on their roles in exporting or importing of electricity. If the tie lines help to export power most of the time, the ELCC of wind energy may increase. However, if the system mainly imports electricity through them, their influences on ELCC might be insignificant.

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